Habit formation as symmetry breaking in the early universe

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Abstract. This paper tries to combine Peirce's cosmology and metaphysics with current understanding in physics of the evolution of the universe, regarded as an ongoing semiotic process in a living cosmos. While the basic property of Life is viewed as an unexplainable Firstness inherent in the initial *iconic* state of the vacuous continuum we shall consider and exemplify two sign developing processes: (a) the transition from *icon* to *index* is considered as a symmetry breaking *emergence* of order actualising one among the possibilities of the iconic vacuum; (b) the transition from *index* to *symbol*, regarded as a habit formation — an adaptation of the surroundings to the order that has emerged. While the iconic state is characterized by *fractal* self-similarity the transitions to index and symbol are modelled by the mean field theory of second order phase transitions.

1. Prebiotic life?

Normally, in biology, the concept of life is considered a property of organisms. E.g., the recent discussion of life on Mars is based upon findings in meteorites from Mars of certain Iron compounds that are known to be formed by the metabolic activities of bacteria known from Earth. Thus, signs of life are identified with traces of organisms. It is also clear from current understanding of physical cosmology that the universe has evolved through a long period before even the presently known chemical elements were formed, — much less orga-

nisms. So, speaking of prebiotic (i.e. pre-organismic) life may seem like a contradiction in terms. However, trying to put a definite mark on the time-axis saying life begins at this point, e.g. where we find the first traces of prokaryotic cells, the basic building blocks of life, will immediately lead to conceptual difficulties. Clearly, such a cut in time can be nothing like a mathematical Dedekind-cut separating the one-dimensional continuum of time in two disjunct sets. If life starts at time *t* there must have been some sort of prebiotic life acting at time *t* minus epsilon. The first eukaryotic cell was preceded by a (in fact, very long) period of prokaryotic life. A period of trials and errors finally succeeding in making the crucial inventions leading to eukaryotic cells (such as the symbiotic inclusion of prokaryotic units like mitochondria). But the prokaryotic cells are also organisms, and, hence, living entities. So, what we have, tentatively, marked as the beginning of life turns out to be a later state in the evolution of organisms from inorganic matter. The same difficulty will turn up however we try to define the beginning, unless we push it as far back as to the initial cosmic event where matter and time is born.

In this paper I want to discuss the pre-biotic (pre-organismic) state of the universe in terms of Peircean semiotics and metaphysics. This implies that the narrow, dualistic distinction of existence vs. non-existence (of life) has to be replaced with the wider framework of Peirce's three ontological categories:

1: possibility, being
2: actuality, existence
3: generality, reality.

In this connection the first category is especially important because it allows us to consider life as an *internal quality of matte*r, endowed with *being*, although it has no external, organismic manifestations and no individual existence, like chance, that also belongs to the first category. Similarly, Edwina Taborsky (2002) considers energy as a firstness that manifests itself only when it is encoded as mass. So, the viewpoint is that *an organism is an encoded form of life, just like mass (e.g. an atom) is an encoded form of energy.*[1]

[1] Thanks to Edwina Taborsky, who, in a private discussion, agreed with this formulation.

2. Tohu Bohu, and the continuum of possibilities

Trying to understand life as a Peircean Firstness is no explanation, for firstness is the category that cannot be explained, only explained away, i.e. as soon as we try to describe it in positive terms we are already speaking about second- and thirdnesses. We may say that life is an internal quality of matter and think, e.g., of the silent life of mitochondria in body cells, but in doing so we presume that these internal organs posses the same inner quality of "extended living feeling" (CP 6.143). The problem is, then, that although pure firstness is utterly undefineable, every account in Peircean terms of the natural history of semiosis has to depart from there. Quoting Peirce (Letter to Christine Ladd-Franklin, August 29, 1891):

> I may mention that my chief avocation in the last ten years has been to develop my cosmology.This theory is that the evolution of the world is hyperbolic, that is, proceeds from one state of things in the infinite past, to a different state of things in the infinite future. The state of things in the infinite past is chaos, tohu bohu, the nothingness of which consists in the total absence of regularity. The state of things in the infinite future is death, the nothingness of which consists in the complete triumph of law and absence of all spontaneity. Between these, we have on our side a state of things in which there is some absolute spontaneity counter to all law, and some degree of conformity to law, which is constantly on the increase owing to the growth of habit. The tendency to form habits or tendency to generalize, is something which grows by its own action, by the habit of taking habits itself growing. Its first germs arose from pure chance. There were slight tendencies to obey rules that had been followed, and these tendencies were rules which were more and more obeyed by their own action. There were also slight tendencies to do otherwise than previously, and these destroyed themselves. To be sure, they would sometimes be strengthened by the opposite tendency, but the stronger they became the more they would tend to destroy themselves. As to the part of time on the further side of eternity which leads back from the infinite future to the infinite past, it evidently proceeds by contraries. (CP 8.317)

The state of *TOHU BOHU* — (a Hebrew concept) can thus be considered as an unlimited sea of unactualized possibilities, — virtual fluctuations, or a "zero collection" of potential properties of the original vacuum. But the vacuum is not a pure firstness (not 1-1, firstness as firstness, but rather 3-1, thirdness as firstness, as Taborsky[2] puts it,

[2] See the fn. 1; also Taborsky 2002, and Peirce (CP 1.366 and 1:473).

because it involves the continuum). A comment by the leading expert on Peirce's philosophy of continuity, Hilary Putnam, will elucidate this. Putnam wrote[3]:

> Dear Ken,
>
> Peirce's point, as I read it, is that in the continuum of pure possibilities, Secondness, that which resists — here, actuality or 'existence' as opposed to possibility — stands out as a discontinuity. If this is right, then the point is to contrast existence with the continuum of possibilities, and not Secondness with Firstness and Thirdness.
>
> (A pure unactualized possibility has no 'quality', and is thus not a First, although the continuum of possibilities is an instance of Thirdness par excellence.) If this is right, the zero collection cannot be a First, nor can it be 'Firstness' either. So the remaining interpretative problem is this: is the 'possibility' represented by the blackboard 'germinal' (the empty collection) or 'developed' (the continuum)? On the basis of my comments on the last two lectures in Reasoning and the Logic of Things, I think it has to be the latter, since the appearance of Secondness, in those lectures, seems in some sense (temporal? or is that only our mode of representing it?) to 'come out of' the continuum at a certain stage.
>
> But these are dark matters!

We can picture the "sea of possibilities" as consisting of domains or islands of different and shifting feelings.[4] Near criticality where the feelings become self-sustaining the domains will have a *fractal* shape. The Harter-Heightway twindragon (Mandelbrot 1977: 66) shown in figure 1 illustrates the *iconic semiosis* on this level. Self-similarity and other-similarity being the dominant force linking signs.

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[3] Posted by Ken Ketner to the discussion forum *peirce-l* on June 5, 2001. Cf. Putnam 1992.

[4] "Feelings", according to Peirce, are intensive qualities like temperature and pressure (firstnesses) having spatial extension (CP 6.133).

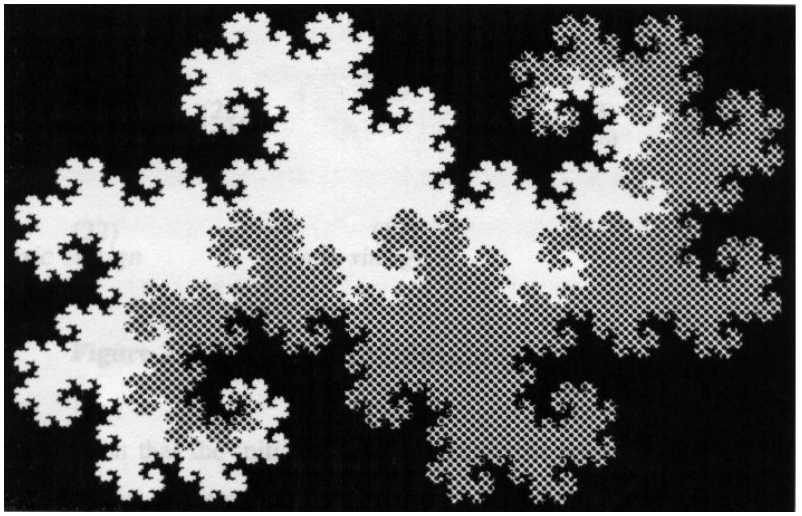

Figure 1. Twindragon made by recursive programming (level 18; P. V. C.).

3. Sign classes and emergence of order

The categories of Peirce are *inclusive* such that secondness includes firstness and thirdness includes secondness and firstness. In this way we arrive at the six classes discussed by Taborsky (Fig. 2).

We have already seen that the initial *Tohu Bohu* state can be discribed as 3-1 Thirdness as firstness. Here we have reversed the numbers to 13 — the first of third. Semiotic evolution proceeds by successive *actualizations* (1 to 2) and *generalizations* (2 to 3) starting with the qualisign (11) through (12) etc. and ending with the symbol (33) (or *mind* as Taborsky calls it). Interpreting Putnams remark such that the initial state is (13) rather than (11)[5] we only have three classes left, (13), (23) and (33), so I choose to call them simply *icon*, *index*, and *symbol*.[6]

[5] The leftover physical theory of evolution from the qualisign (11) to the icon of the continuum (13) may be contained in the modern *M*-theory of superstrings.

[6] Instead of iconic, indexic, symbolic, *legisigns*.

We looked at the iconic state through the twindragon of figure 1 where the different domains or islands of feeling associate by similarity to self and others.

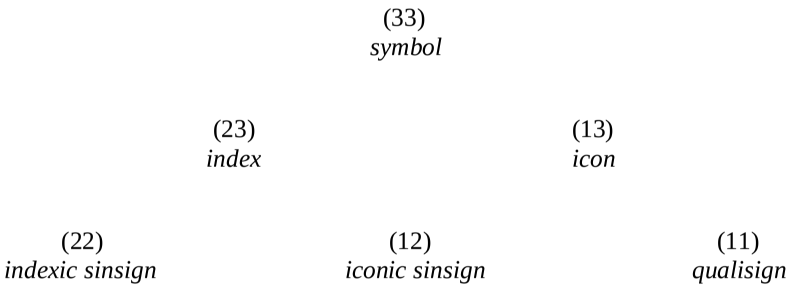

Figure 2. The 6 classes of signs.

The next step to consider is the transition to the indexic state when the symmetry is broken such that one particular feeling or internal order begins to monopolize the picture to the exclusion of all others. This is a critical transition well known from physics of second order phase transitions from disorder to order. The most well known example is the condensation of vapour to form droplets of liquid. The symmetry-breaking event is here the formation of a surface, i.e. a discontinuity of density separating the rarefied vapour from the denser liquid[7] This separation of the inside from the outside of a bubble is an example of *the ontological cut* discussed by Taborsky. It seems relevant to biology because it resembles the formation of a cell-membrane. When lipid molecules having a hydrophobic end and a hydrophilic end are suspended in water they will tend to reorient themselves to be parallel and form a closed membrane around a bubble of water. In both cases of droplet-formation there will be an *ordering field* — a surface tension acting to amplify the symmetry breaking operation of the surface or membrane. The idea of an *order parameter* that creates an *ordering field* which, in turn, facilitates growth of the order parameter is in physics summarized in the so called *mean field theory of (2nd order) phase transition.* An example is the Curie-Weiss theory of the

[7] See the discussion in Christiansen 2000.

transition from paramagnetism to ferromagnetism summarized in the positive feedback loop on Figure 3.

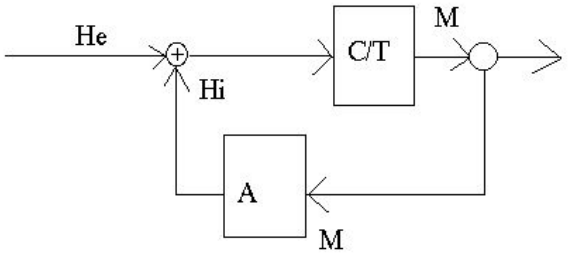

Figure 3. Positive feedback look illustrating the Curie-Weiss mean field theory of ferromagnetism.

Well above criticality the system exhibits a linear relation between the magnetization M and the magnetic field H:

$$M = \chi H$$

where χ is the paramagnetic susceptibility:

$$\chi = C/T,$$

C being the material-specific Curie-constant and *T* the absolute temperature. This describes the statistical balancing between the ordering coupling to the magnetic field (*C*) and the disordering thermal motion (*T)*. The order parameter *M* is assumed to create an internal ordering field H_i that combines additively with the external field H_e. the whole diagram of figure 3 corresponds to the equation

$$M = (C / T) (H_e + AM) \qquad 1$$

Solving for *M* we get

$$M = C H_e / (T - T_c) \qquad 2$$

where $T_c = CA$ is the critical temperature.

Thus, for *T* above T_c we have paramagnetic behaviour with a slightly enhanced susceptibility. At T_c, however, it becomes possible to have a non-vanishing order parameter *M* — a spontaneous magne-

tization — even in the absence of an external ordering field H_e. Below T_c the linear model of figure 3 does not apply.

What really happens at and below the critical temperature is hard to describe quantitatively. At T_c the domains are characterized by fractal self-similarity and long-range correlations. Averages of powers of the mean field are unequal to mean values of the same powers of the field. So called *renormalization theories* have shown that the mean field description is correct in four dimensional euclidean space (wherever that may be), but the case of three dimensions defies description, except for the transition to superconductivity, where the mean field theory happens to be nearly exact[8] (as well as for gravitational collapse, sec. 6). In all cases the disorder-order transition is a *bifurcation*, i.e. there is more than one way in which the order parameter can be stabilized below T_c and a symmetry breaking *random choice* determines the outcome. For the ferromagnetic transition the order parameter M is a vector that can point any direction in space, but below T_c the spontaneous magnetization must point in a certain direction dependent on which domain happened to be dominating for the ordering field at the transition. The random choice made at T_c serves in this way to establish a *habit* that cannot be broken once it is formed. According to Peirce's cosmology, as outlined, e.g. in the previously quoted letter to Christine Ladd-Franklin even the fundamental laws of nature have a history of being formed in this way as habits based on an initial random choice, and the element of chance still prevails such that none of these laws are obeyed *exactly*. Habit formation is then the finishing step of natural semiosis, the step from index to symbol of figure 2. In the following section we shall briefly consider some important symmetry breaking and habit forming transitions in the prebiotic (pre-organismic) state of the physical universe.

A habit is formed as an attractor of a dynamic system, and its realization is always accompanied by energy dissipation and entropy production.

[8] As demonstrated by the striking success of the phenomenological theory of superconductivity by the Soviet physicists L. D. Landau and V. L. Ginzburg, (Ginzburg, Landau 1950).

4. The first flash

The energy in our present universe is divided among several fields and their quanta of excitation, i.e., particles. The main division is between matter-fields and electromagnetic radiation, carried by massless photons. The quanta of the matter-fields can be divided in two main types: Fermions obeying Pauli's exclusion principle with half-integer spins, and massive bosons with integer spins. Besides, the main part of the mass is believed to be associated with "dark matter" of an unknown nature. The known Fermion fields include *six types of quarks (u, d, s, c, t, b)* and *six types of leptons (e, μ, τ,* and their neutrinos ν_e, ν_μ, ν_τ).[9]

These particles interact in four ways, *weak, strong, electromagnetic, and gravitational* carried by bosons, resp. (massive vector bosons and the scalar Higgs-particle (undetected), gluons (8 kinds), massless photons, and gravitons).

The graviton has not been detected but is known to be without charge and mass and to have spin 2. The absence of mass of the photon and the graviton explains why electromagnetism and gravitation have infinite range. On the other hand, the weak interaction is of very short range, which means that its quanta — the vector bosons (W and Z) must be rather heavy[10] (about 100 GeV, confirmed by experiments at CERN). The finite rest-mass of the vector bosons has presented a big problem for the standard model, according to which they should be massless. The problem was solved by postulating the existence of the *Higgs-boson*. These particles are assumed to form a *Bose-condensate* with a definite value of the scalar *Higgs-field, H*). Just like the condensate of electron-pairs in superconductors give the photons a finite range, the *H*-field interacts with the vector bosons and give them a finite range. In the absence of a *H*-field there would be no way to distinguish between the weak and the electromagnetic interactions, so *H* may be considered a symmetry breaking ordering field just like the mean internal field in the Curie-Weiss theory of ferromagnetism (Figure 3). According to the so-called *inflation-theory* by

[9] It is tempting, therefore, to use the six classes of signs (Figure 2) as a key to classification of elementary particles. This line of thought will be pursued in a forthcoming paper by the author.

[10] The range of a force field mediated by boson-quanta is inversely proportional to the mass of the bosons.

Alan Guth the nucleation of H is a very violent event that creates the universe by an anormous blow-up of an initial small domain of non-vanishing H. We can picture the vacuum-energy as a function of H like shown in Figure 4.

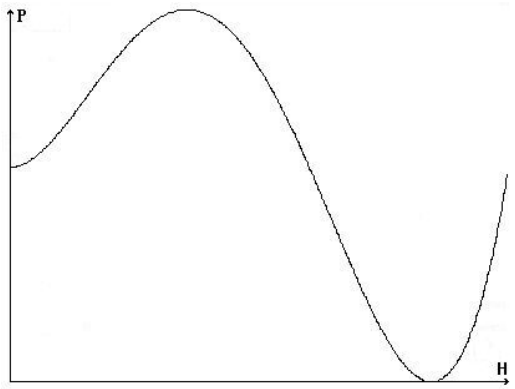

Figure 4. Vacuum potential P as function of the Higgs-field H.

The potential has a minimum for $H = 0$ corresponding to the initial vacuum state before inflation (sometimes called the *false vacuum*). However, there is a lower minimum at a finite value of H, separated from the first minimum by a potential-barrier. This barrier will prevent transition to the lower minimum until some fluctuation lifts the system over the barrier. A *thermal* fluctuation presupposes that the temperature has a finite value in the false vacuum, which may be a dubious assumption, but even at zero temperature the system may penetrate the barrier by *quantum mechanical tunnelling*. The vacuum potential P is an even function of H, so there is a symmetry breaking in the choice between a positive or a negative value of H. As soon as a domain of the system penetrates the barrier there will be enough energy released to help the transition spread as an avalanche to the whole potential universe like the growth of crystallization spreading in a super-saturated solution or a supercooled liquid from a single crystal germ. The transition creates a lot of entropy, the universe blows up by more than fifty orders of magnitude and is born in a very hot state

after about 10^{-33}s. This state after inflation is then the starting point (time zero) of the standard "big bang" model of evolution.

5. Subsequent symmetry breakings

Just after the inflation period the universe is a very hot fireball with all kinds of particles and a temperature of more than 10^{15} K sufficient to produce free vector bosons and Higgs particles. But the state is cooling rapidly under adiabatic expansion, and as soon as the Higgs field settles down the previous symmetry between electromagnetic and weak interactions is broken to the habit of the force-laws known today. Another symmetry that is rapidly broken is the symmetry between particles and antiparticles. In the initial fireball there must have been a small random surplus of particles over antiparticles, and this difference will prevail after the pairwise annihilation processes, such that all antimatter has disappeared, except for anti-quarks in compounds like mesons and hadrons. Most quarks are soon bound in stable triplets to form hadrons, i.e. protons and neutrons. These two nucleons, the building blocks of all the nuclei of chemical elements are balanced by the β-process

$$n\_e + p + \nu \qquad 3$$

whereby a neutron *n* decays to a proton *p*, an electron *e*, and a neutrino *ν*, and the reverse process. The neutrinos only interact weakly, through this process, with other particles, and, as they are nearly massless[11] and, therefore moving with near-light-speed they disappear from every finite part of the universe after a couple of minutes, so that the balance of the reactions (3) gets frozen and the *n*/*p*-ratio becomes fixed — another habit-forming symmetry-break has occurred.

[11] Recent experiments in Japan have shown that at least one of the three kinds of neutrinos (ν_e, ν_μ, and ν_τ) have restmasses about 10 eV, 0.002% of the electron's mass.

6. Entropy and gravity in the ageing universe

The expansion of the initial fireball is in the standard *Big Bang* model described as *nearly adiabatic*, i.e. without entropy production. According to thermodynamics, however, no habit formation (i.e. no evolution at all) can take place without entropy production, so the use of the word *adiabatic* just means that the entropy produced after inflation is very small compared to the entropy produced in the first flash of inflation. While Boltzmann and other pioneers saw the concept of entropy as signifying the *heat death* of the universe the current view is closer to Peirce's vision of a *heat birth* and a *cold death*. The expansion may be described by an *increasing scale factor ξ(t) that stretches everything proportional to the distance* from every arbitrary chosen "centre". During inflation ξ(t) had an exponential increase, but afterwards it is replaced with a much slower power-law increase. The wavelenghts of the photons in the radiation field are stretched in the same proportion as all other distances, so the temperature of the background radiation decreases inversely proportional to ξ(t).

In the beginning phase when the radiation is still hot enough to ionize hydrogen the matter will exist as a *plasma* with the charged particles, electrons and protons uniformly dispersed in electromagnetic radiation. The photons cannot reach far before they are absorbed by the charged particles, so the universe is opaque. The matter particles (*e* and *p*) cannot clump together because they are continually scattered by photons. *Gravitation* is in a slumbering state of Peircean firstness, because the uniformity of matter distribution makes it pull equally in all directions, cancelling itself out in every point. The next significant symmetry breaking occurs after about 300,000 years when the temperatur drops below the ionization point of hydrogen. When the matter gets bound to the atoms of electrically neutral atoms of hydrogen and helium it ceases to interact with the photons, and the universe becomes transparent. A homogeneous distribution of neutral matter is unstable under gravitational collapse, so a randomly formed lump of greater density will attract surrounding matter and create an increasing ordering field of gravity, enhancing the lumping tendency as described by the mean field theory of figure 3. Thus, the symmetry breaking gravitational collapse leads to the formation of galaxies and stars. The concentration of matter creates entropy and rises the temperature of matter compared to the continually expanding and

cooling radiation field. With light emitting stars on a dark background the universe is beginning to look familiar and the stage is set for a biochemical and organismic evolution. However, the biosemiotic perspective of symmetry breaking and habit formation still applies.

7. Concluding remarks

The point of view in this paper is that modern theories of the physics of the early universe fits together with Peirce's cosmology to contribute to the biosemiotic natural history of signification. This should not be regarded as a reductionistic attempt to place physics as a basis for biosemiotics but rather as an elaboration of the idea that physical cosmology needs a semiotic perspective in order to enter a fruitful dialogue with biology and other sciences. In accordance with scientists like Manfred Eigen and Ilya Prigogine I believe that evolution of living signs is *indeterminate but inevitable* and if it seems too radical to regard life as a first, an internal quality of matter, I ask for a better view that doesn't make it seem utterly strange that the universe has evolved to produce humans and other sign using creatures.

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Привыкание как ломка симметрии в раннем универсуме

В статье делается попытка связать космологию и метафизику Пирса с распространенным в современной физике пониманием эволюции универсума, рассматривая ее как семиотический процесс в живом универсуме. Если считать главным свойством жизни необъяснимую Первичность, которая исходит из первичного иконического состояния в пустом универсуме, то можно выделить два процесса развития знака: а) переход от икона к индексу как возникновение упорядоченности посредством ломки симметрии (которая актуализирует одну из возможностей иконического вакуума); б) переход от индекса к символу, что являет собой привыкание (habit) — адаптацию окружения к появившемуся порядку. Если иконическое состояние характеризуется *фрактальным* самоподобием, то переходы к индексу и символу моделируются теорией фазовых переходов второго порядка.

Habitueerumine kui sümmeetria murdumine varases universumis

Artiklis püütakse seostada Peirce'i kosmoloogiat ja metafüüsikat praeguse füüsikalise arusaamaga universumi evolutsioonist, vaadeldes seda kui semiootilist protsessi elavas universumis. Kui pidada elu peamiseks omaduseks seletamatut Esmasust, mis pärineb algsest ikoonilisest seisundist tühjas kontiinuumis, saab vaadelda kahte märgi arenguprotsessi: (a) üleminek ikoonilt indeksile kui sümmeetria murdumisega korrastatuse teke, mis aktualiseerib ühe ikoonilise vaakuumi võimalustest; (b) üleminek indeksilt sümbolile, mis on habitueerumine — ümbruse adapteerumine ilmunud korrale. Kui ikooniline seisund on iseloomustuv fraktaalse enesesarnasusega, siis üleminekud indeksile ja sümbolile on modelleeritavad teist järku faasiüleminekutena.